

Fluorescence imaging of petroleum accelerants by time-resolved spectroscopy with a pulsed Nd-YAG laser

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Abstract

In this paper, fluorescence of petroleum accelerants such as kerosene, motor gasoline and diesel fuel were measured by the nanosecond time-resolved spectroscopy with a pulsed Nd-YAG laser. The excitation wavelengths are 266 nm (fourth harmonic generation) and 355 nm (third harmonic generation). Fluorescence was detected by a cooled CCD camera with an image intensifier. From these measurements, fluorescence lifetime was determined. We have also shown that the principal component of fluorescence spectra of kerosene is dimethylnaphthalene when excited with 266 nm laser light. For gasoline and diesel fuel, there exist other hydrocarbons which emit fluorescence. There is a significant difference among fluorescence spectra of kerosene, gasoline and diesel fuel. These results can be used for the identification of petroleum accelerants. We have also measured fluorescence spectra of various background materials such as newspaper, cardboard, carpet, cotton glove, wood board and various kinds of paper. We have shown that there exists a significant difference between petroleum accelerants and these background materials in fluorescence spectra and their lifetimes. By using such a difference, petroleum accelerants can be detected effectively even when they are on the fluorescent background materials which sometimes disturb the detection by emitting strong fluorescence. We have shown that petroleum accelerants on various background materials can be visualized by the time-resolved fluorescence imaging. Taking actual fire cases into account, the influence of heat to kerosene was studied. By heating, the fluorescence intensity of kerosene reduced for 266-nm excitation, but it increased for 355-nm excitation. For spectral profile, no change was observed for 266-nm excitation but there is a difference between non-heated kerosene and heated kerosene for 355-nm excitation. The lifetime seems to increase slightly by heating for 266-nm excitation but it is almost constant for 355-nm excitation. Imaging heated kerosene on burned background materials was examined and it is confirmed that heated kerosene can be detected on burned materials by the time-resolved method with an appropriate band-pass filter.

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1. Introduction

Petroleum accelerants such as kerosene, motor gasoline and diesel fuel are often encountered in arson cases. In these

cases, finding petroleum accelerants is quite important for estimation of fire causes. Petroleum accelerants are usually detected by gas chromatography. However, petroleum accelerants consist of hydrocarbons which emit fluorescence. Therefore, detecting petroleum accelerants by fluorescence is expecting.

In order to detect the fluorescence of petroleum accelerants, Takeuchi et al. [1] have investigated the optical

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detection method of inherent fluorescence using a CCD camera with an image intensifier. They have shown that it is possible to detect petroleum accelerants in fire residues by this method. However, since there exists fluorescence of various background materials, it is sometimes difficult to detect fluorescence of petroleum accelerants.

Time-resolved fluorescence spectroscopy is effective to overcome such a problem [2]. This method utilizes the difference of fluorescence lifetime between petroleum accelerants and backgrounds, i.e., by observing with an appropriate delay time, the fluorescence from petroleum accelerants can be detected clearly because of the elimination or reduction of background fluorescence. Time-resolved fluorescence is used for biochemistry, forensic science and many other fields [3–5].

However, since the fluorescence of petroleum accelerants is not so strong, it needs a strong exciting light source and a high sensitive detector. In this paper, we have studied the time-resolved fluorescence spectroscopy and imaging using a pulsed Nd-YAG-laser and a cooled CCD camera with an image intensifier and have shown that our system is effective for the detection of petroleum accelerants.

2. Methods

The block diagram of our system is depicted in Fig. 1. The system consists of a pulsed Nd-YAG laser [Continuum, Surelite I-20], a cooled CCD camera with an image intensifier [Roper Scientific, PI-MAX 1K-RB-FG-43] and a spectrometer [Acton Research Corporation, SpectraPro-300i]. The fourth and the third harmonic waves of the Nd-YAG laser, whose wavelengths are 266 nm and 355 nm, respectively, are used to excite the fluorescence of samples. The frequency of the laser pulse is 20 Hz and the width of individual pulse is about 5 ns. Its energy is about 40 mJ for 266 nm and 60 mJ for 355 nm, respectively. Laser pulses were irradiated onto samples after expanding the beam with

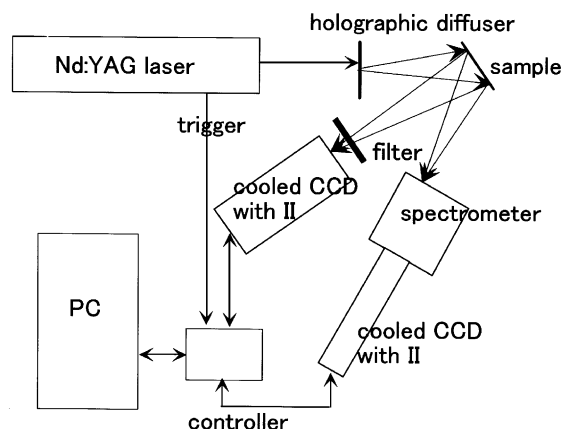


Fig. 1. Block diagram of the time-resolving fluorescence imaging and spectroscopy system.

a holographic diffuser or a quartz lens. The size of the irradiated area depends on the distance between the lens or the diffuser and a sample. For example, the diameter of the irradiated area is about 3–10 cm at the point of 1 m from the lens or the diffuser. The CCD camera is cooled to -20°C to suppress the thermoelectric noise. Samples are kerosene, motor gasoline and diesel fuel which are available at commercial gas stations.

With this system, fluorescence images and their spectra both can be measured. When observing a fluorescence image, approximately 0.5 ml of each samples are dropped onto a thin layer plate or substrates and observed by the CCD camera with an image intensifier after filtering the incident laser light by a high-pass filter which passes the fluorescence emission. The image intensifier can be gated faster than 2 ns.

Time-resolved fluorescence images are obtained with the use of gated detection of the fluorescence emission. When a difference of lifetime exists between a sample and backgrounds, the image intensifier is triggered at the appropriate delay time which is set to the value between the lifetimes of samples and backgrounds. The gating control of the exposure time of the CCD camera and the delay time of observa-

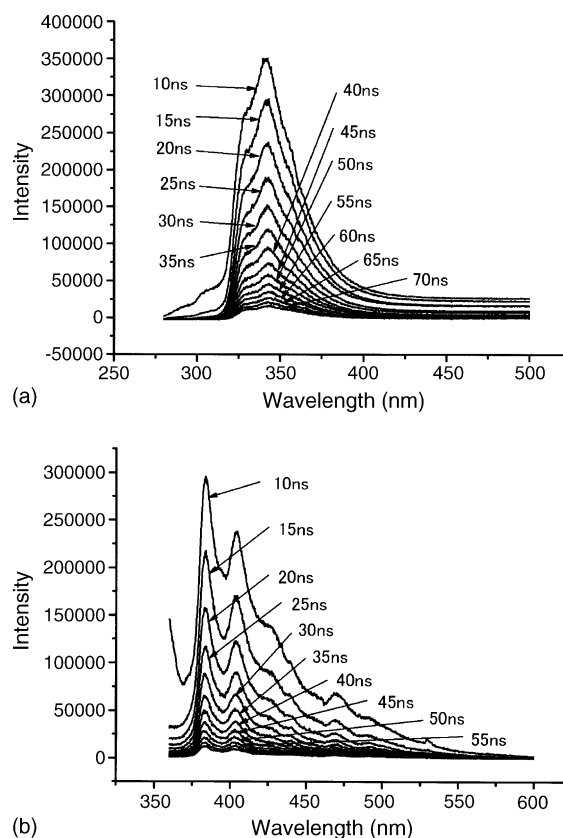


Fig. 2. (a) Time-resolved fluorescence spectra of kerosene with 266-nm excitation and (b) time-resolved fluorescence spectra of kerosene with 355-nm excitation.

tion is done by a programming timing generator (PTG) and a personal computer. When conducting fluorescence spectroscopy, approximately 4 ml of each sample are poured into a rectangular quartz cell. In this case, the CCD camera is attached to a grating spectrometer which has a grating monochromator with 1200 g/mm. Spectra are measured also by the CCD camera with the same gating control as the case of obtaining fluorescence images. This CCD has 1024×1024 pixels of $13\text{-}\mu\text{m} \times 13\text{-}\mu\text{m}$ pixel size. The wavelength resolution is 0.137056 nm per pixel. Therefore, e.g., wavelength range is from 279.242 nm to 420.438 nm when the center of monochromator is set to 350 nm. In order to obtain wide spread spectrum, it is necessary to measure twice or more with different wavelength range and glue each spectrum adequately. Obtained spectra were digitized in 16 bit. Background spectra, which consist of noise, can be subtracted at each measurement. When fluorescence signal is weak, measurement was performed several times and all measurements are accumulated to suppress noise. In our current experiments, measurement time is 1 s in most cases. In these cases, the total exposure time becomes 200 ns since the pulse frequency is 20 Hz and the gate width is 10 ns.

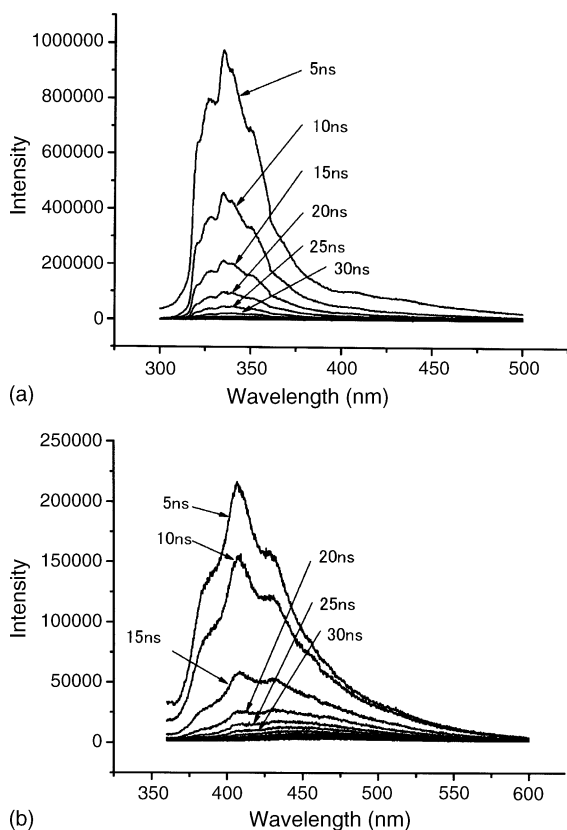


Fig. 3. (a) Time-resolved fluorescence spectra of gasoline with 266-nm excitation and (b) time-resolved fluorescence spectra of gasoline with 355-nm excitation.

3. Results

3.1. Time-resolved fluorescence spectra of petroleum accelerants by a Nd-YAG laser excitation

Time-resolved fluorescence spectra of kerosene, gasoline and diesel fuel excited by 266 nm and 355 nm laser light are shown, respectively in Figs. 2–4.

In the case of kerosene and gasoline for 266 nm excitation, the peak wavelength is lower than 350 nm, whereas for diesel fuel, it is higher than 350 nm. Except for kerosene for 266-nm excitation, spectra have several components. Kerosene has two components for 266-nm excitation but its profile is simple.

Fluorescence of gasoline shows several small shoulders for 266-nm excitation and is quite different from those of kerosene and diesel fuel for both 266-nm and 355-nm excitations. Fluorescence of gasoline decays very fast, which is also different from that of kerosene and diesel fuel.

3.2. Fluorescence lifetime

In Figs. 5–7, the fluorescence intensity of kerosene, gasoline and diesel fuel are plotted against the delay time

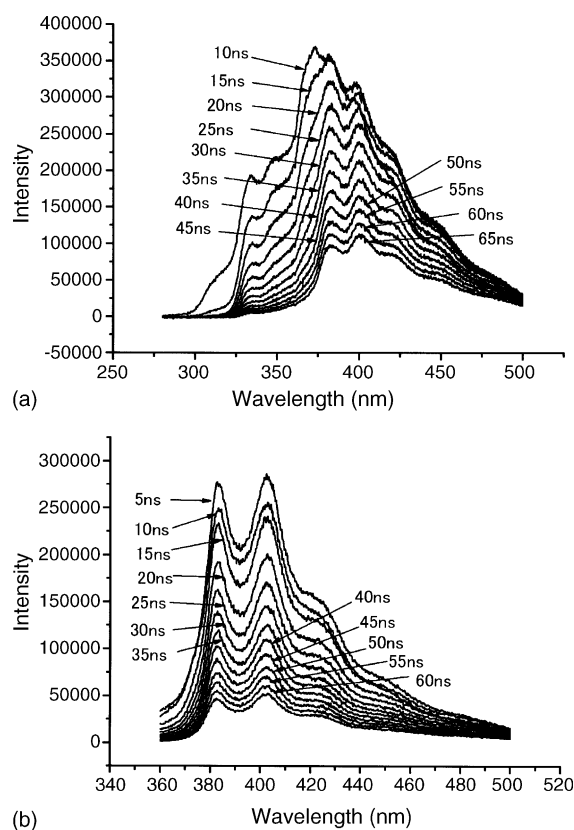


Fig. 4. (a) Time-resolved fluorescence spectra of diesel fuel with 266-nm excitation and (b) time-resolved fluorescence spectra of diesel fuel with 355-nm excitation.

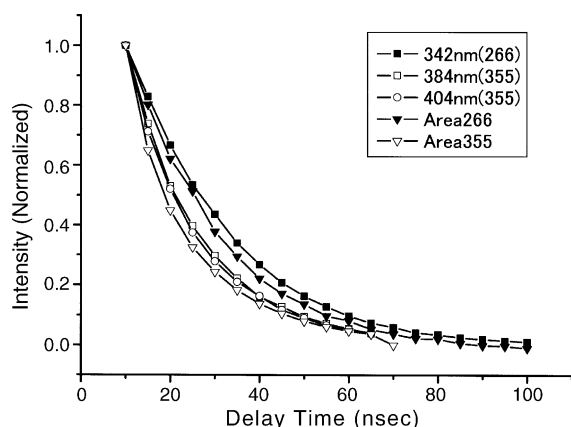


Fig. 5. Fluorescence intensity of kerosene with respect to the delay time.

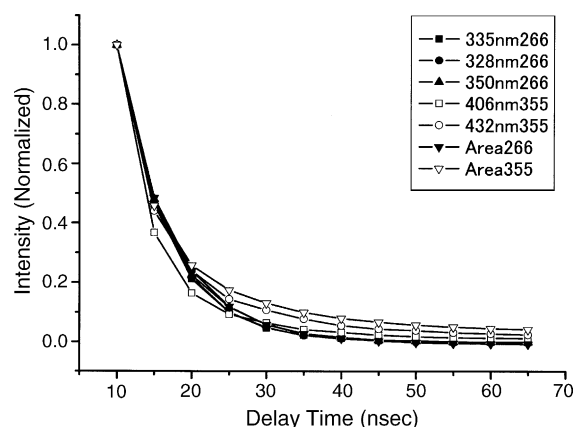


Fig. 6. Fluorescence intensity of gasoline with respect to the delay time.

for various peak wavelengths. The lifetime was obtained by fitting an exponential function $I(t) = I_0 e^{(-t/\tau)} + c$ to these data, where τ denotes a lifetime and I_0 denotes the intensity at delay time 0. By this fitting, the lifetime was determined as shown in Table 1. As is seen from Table 1, the lifetime for gasoline is approximately 6 ns for both 266-nm and 355-nm excitation and is shorter than those of kerosene and diesel fuel. For kerosene, the fluorescence lifetime is about 20 ns for 266-nm excitation and 16 ns for 355-nm excitation. For diesel fuel, there are two components, the long lifetime component (about 40–60 ns) and the short lifetime component (about 20–26 ns) for 266-nm excitation. For 355-nm excitation, the lifetime is approximately 27 ns.

In Figs. 5–7, another intensity plots (area 266, area 355) which were obtained by integrating all spectral intensity values of each time-resolved fluorescence spectra are also shown. By fitting an exponential function to these data, the fluorescence lifetimes of kerosene, motor gasoline and diesel fuel are 21.6 ns, 6.5 ns and 25.5 ns for 266-nm excitation and 12.6 ns, 6.4 ns and 26.8 ns for 355-nm excitation, respectively. These values show the averaged lifetime. From these results, the fluorescence lifetime is estimated as approximately 20 ns (266 nm) or 13 ns (355 nm) for kerosene, 6 ns for motor gasoline and 26 ns for diesel fuel on average.

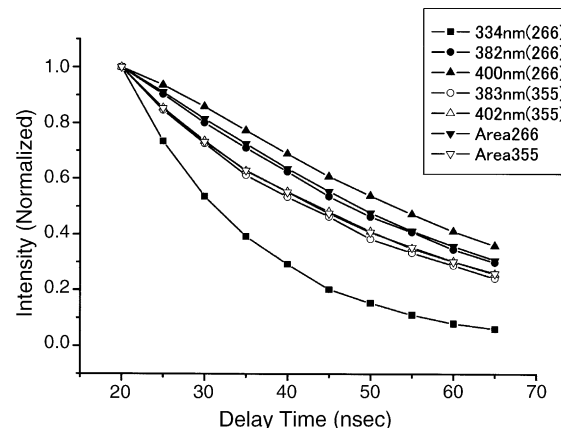


Fig. 7. Fluorescence intensity of diesel fuel with respect to the delay time.

3.3. Fluorescence of background materials

Petroleum accelerants exist on background materials in actual arson cases. Therefore, fluorescence of background materials is simultaneously observed with those of petroleum accelerants. In Fig. 8, fluorescence spectra of various

Table 1
Fluorescence lifetimes for kerosene, gasoline and diesel fuel

Excitation wavelength	Lifetime for kerosene (ns)	Lifetime for gasoline (ns)	Lifetime for diesel fuel (ns)
266 nm	18.5 ± 0.2 (342 nm)	6.00 ± 0.03 (320 nm)	19.4 ± 0.5 (334 nm)
	21.6 ± 0.3 (area)	6.55 ± 0.01 (328 nm)	26.6 ± 0.6 (354 nm)
		6.58 ± 0.02 (335 nm)	42.5 ± 1.6 (377 nm)
		6.12 ± 0.03 (350 nm)	59.2 ± 4.3 (398 nm)
		6.5 ± 0.1 (area)	25.5 ± 0.8 (area)
355 nm	15.9 ± 0.2 (384 nm)	4.5 ± 0.1 (385 nm)	26.6 ± 0.9 (383 nm)
	15.1 ± 0.2 (404 nm)	5.0 ± 0.2 (406 nm)	27.3 ± 1.1 (402 nm)
	12.6 ± 0.4 (area)	6.2 ± 0.3 (432 nm)	26.8 ± 1.0 (area)
		6.4 ± 0.3 (area)	

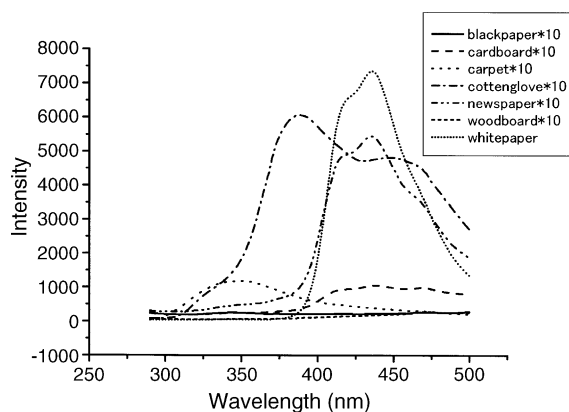


Fig. 8. Fluorescence spectra of various background materials.

Table 2

Fluorescence lifetimes of various background materials for 266-nm and 355-nm excitation

Background material	Lifetime (266-nm excitation) (ns)	Lifetime (355-nm excitation) (ns)
Carpet	3.32 ± 0.08	4.47 ± 0.06
Cotton glove	4.77 ± 0.06	3.19 ± 0.06
Blanket	3.05 ± 0.09	4.39 ± 0.04
Whitepaper	1.67 ± 0.05	2.26 ± 0.01
Newspaper	1.47 ± 0.02	2.31 ± 0.01
Cardboard	1.65 ± 0.05	2.50 ± 0.02
Towel	1.70 ± 0.02	2.49 ± 0.01

background materials excited with 266 nm laser light are shown. For a whitepaper and a cardboard, fluorescence exists above 400 nm wavelength region which is different from fluorescence of petroleum accelerants. Fluorescence of a blackpaper seems very weak. This may be attributed to the absorption of fluorescence of paper by black materials. In Table 2, fluorescence lifetime of various background materials are shown. Fluorescence lifetime is about 2 ns for papers and a towel, and 3–5 ns for fiber products. It can be recognized that fluorescence lifetime of background materials in Table 2 are shorter than those of petroleum

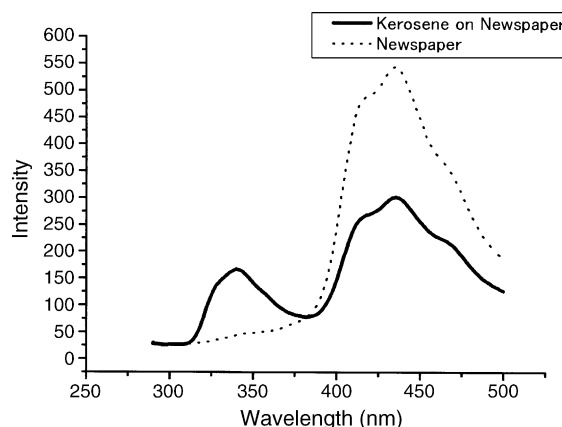


Fig. 9. Fluorescence spectra of kerosene on a newspaper excited by 266-nm laser light.

accelerants even for cotton glove and carpet. This means that petroleum accelerants can be detected by the time-resolved fluorescence imaging method.

3.4. Time-resolved fluorescence imaging with backgrounds

As we have seen in previous sections, there is a difference of the fluorescence lifetime and the wavelength region between petroleum accelerants and background materials such as newspapers, papers, towels, clothes, wood, carpets, blanket etc. Based on these results, we have conducted experiments of visualizing petroleum accelerants on background materials by time-resolved imaging.

In Fig. 9, fluorescence spectra of newspaper and kerosene on newspaper are shown. As is seen from Fig. 9, the main part of fluorescence emitted from newspaper ranges from 390 nm to over 500 nm. Its lifetime is about 1.5 ns. On the other hand, when kerosene exists, there is a broad fluorescence band at the wavelength from 300 nm to 400 nm.

Although fluorescence of kerosene might be detected by using only time-resolving technique, it is better to utilize the

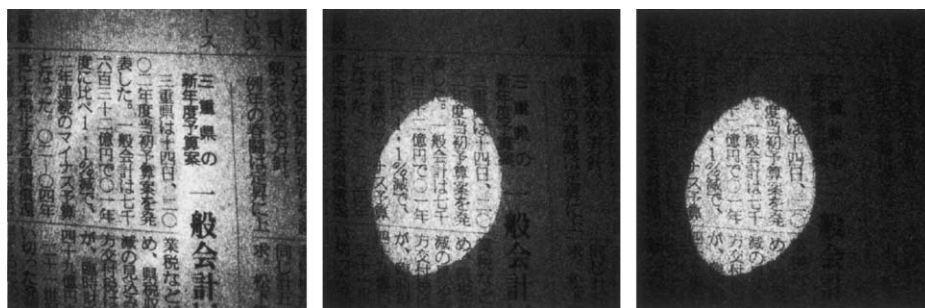


Fig. 10. Time-resolved fluorescence images of kerosene on newspaper for 5 ns, 10 ns and 15 ns delay. From left to right: delay 5 ns, delay 10 ns and delay 15 ns.

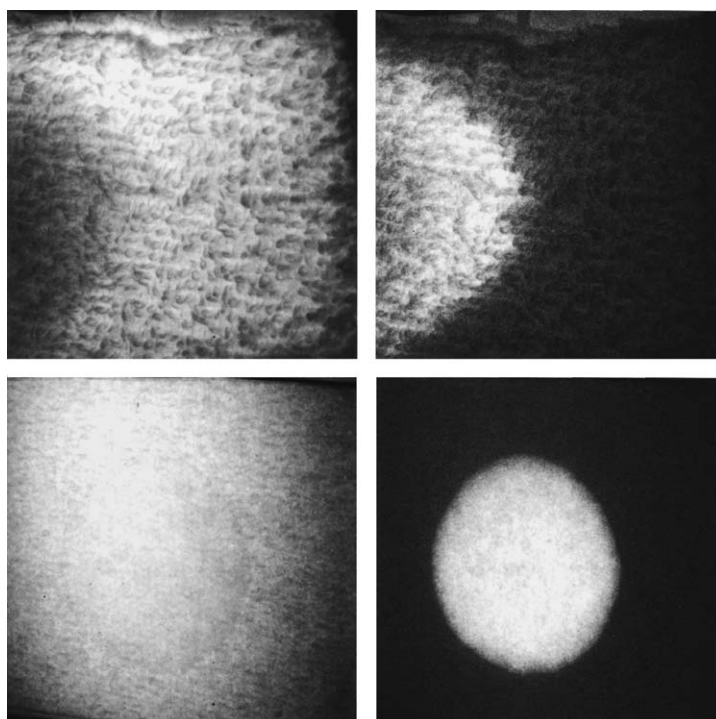


Fig. 11. Time-resolved fluorescence images of kerosene on a towel and a whitepaper. Upper: on a towel, left (5 ns delay) and right (15 ns delay); lower: on a whitepaper, left (5 ns delay) and right (15 ns delay).

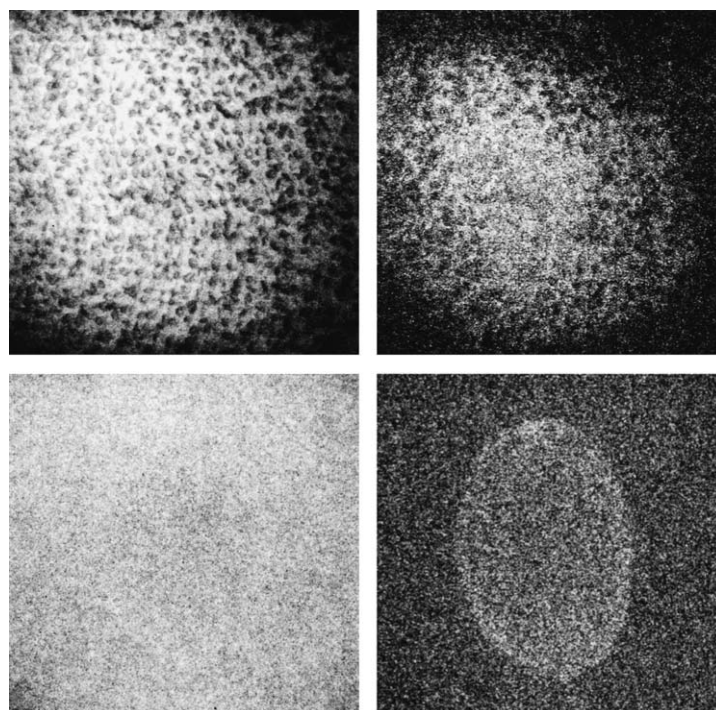


Fig. 12. Time-resolved fluorescence images of gasoline on a towel and a whitepaper. Upper: on a towel, left (10 ns delay) and right (20 ns delay); lower: on a whitepaper, left (10 ns delay) and right (15 ns delay).

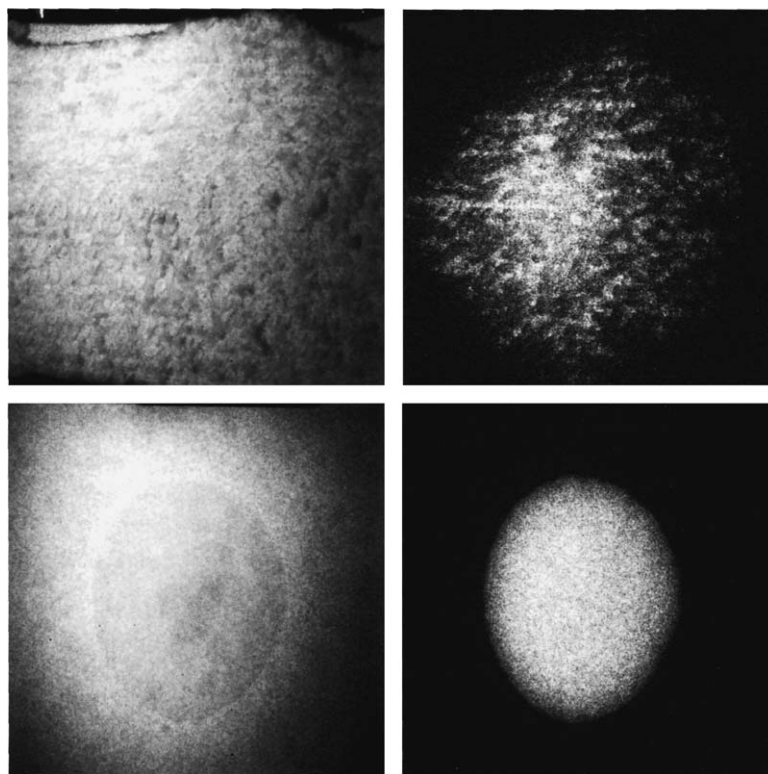


Fig. 13. Time-resolved fluorescence images of diesel fuel on a towel and a whitepaper. Upper: on a towel, left (5 ns delay) and right (15 ns delay); lower: on a whitepaper, left (5 ns delay) and right (15 ns delay).

difference of wavelength region because there are cases in which the fluorescence intensity is weak due to smaller amount of petroleum accelerants than background materials. From this point of view, it is better to excite fluorescence by 266 nm light, because wavelength region may be divided into two regions at about 400 nm wavelength. Main fluorescence from petroleum accelerants can be measured by using a low-pass filter which is transparent below 400 nm. Therefore for detecting fluorescence of petroleum accelerants, we have used 266 nm excitation.

In Fig. 10, time-resolved fluorescence images of kerosene on a newspaper are shown for delay time 5 ns, 10 ns and 15 ns. Since the fluorescence from newspaper is strong, the fluorescence image of kerosene is not clear for the delay time 5 ns but it becomes visible when the delay time becomes longer than 10 ns. In Figs. 11–13, time-resolved fluorescence images of kerosene, gasoline and diesel fuel on a towel and a whitepaper are shown for delay time 5 ns or 10 ns and 15 ns or 20 ns. In each case, images of petroleum accelerants are not recognized clearly for 5 ns or 10 ns delay but they became visible for 15 ns or 20 ns delay. In Fig. 14, time-resolved fluorescence images of kerosene on various background materials are shown. In this figure, the delay time is 15 ns for all. Thus by the time-resolved fluorescence imaging, petroleum accelerants are clearly detected.

3.5. Effects by heating

When petroleum accelerants were used in actual fire scenes, petroleum accelerants would be heated by fire and their properties may be varied by heating. In order to apply our method to actual cases, it is necessary to show our method is effective to heated samples. In actual arson cases, kerosene is used most often in Japan. Therefore in this section, the effect of heating to kerosene is described. Heated samples were prepared by burning kerosene for 30 s, 3 min and 5 min and collecting residue. Since kerosene will be vaporized with long heating, it is difficult to obtain the heated sample with more than 5 min. In Fig. 15, samples of heated kerosene are shown. By heating, kerosene turns its color to brown. As the heating time becomes longer, the color of kerosene becomes darker. In Fig. 16, gas-chromatography charts are shown for kerosene without heating and with 5 min heating. From Fig. 16, it is recognized that components with a low boiling point were vaporized and eliminated. In Figs. 17 and 18, fluorescence spectra are shown for these heat-varied kerosene samples. In the case of 266-nm excitation (Fig. 17), fluorescence intensity becomes lower as the heating time increases. There is little change in spectral profile. On the other hand, for 355-nm excitation (Fig. 18), fluorescence intensity increases as heating proceeds. There is a difference between non-heated

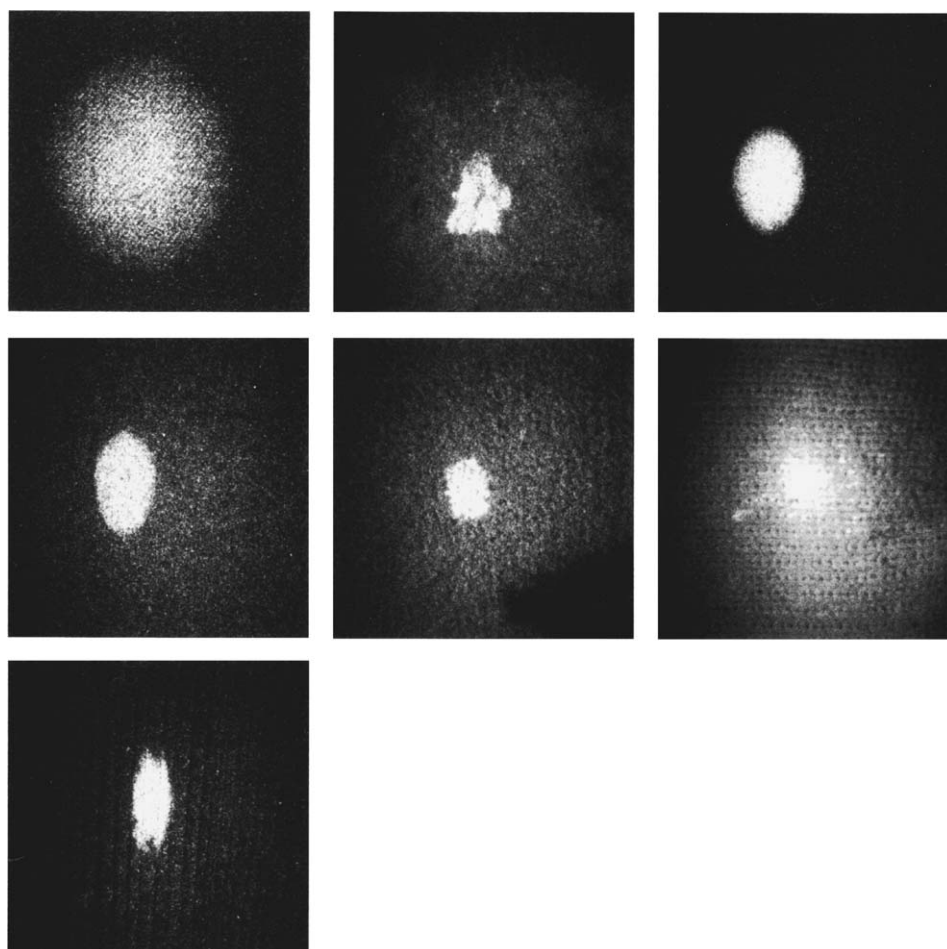


Fig. 14. Time-resolved fluorescence images of kerosene on various background materials. The delay time is 15 ns for all. From left upper corner: blue jacket, blanket, blackpaper, cardboard, carpet, cotton glove and wood.

kerosene and heated kerosene in spectral profile. Lifetimes for heated kerosene are shown in Fig. 19. The lifetime was approximately 22 ns and 8 ns for 266-nm excitation and

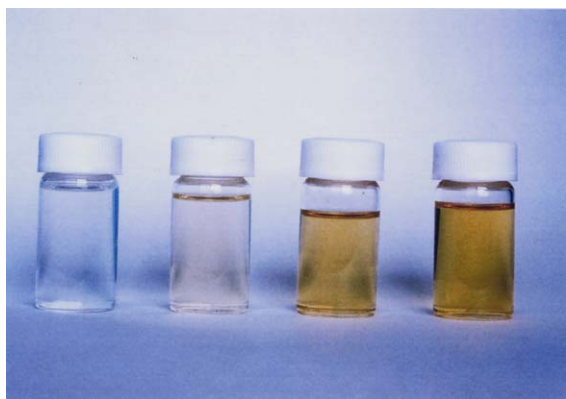


Fig. 15. Samples of non-heated and heated kerosene. From left, non-heated, heated 30 s, 3 min and 5 min.

355-nm excitation, respectively. These values were obtained by fitting an exponential function to the plot of the area intensity. Therefore, these values represent the averaged lifetime. The lifetime seems almost constant and does not depend on the heating time for 355-nm excitation. However for 266-nm excitation, the lifetime seems to increase slightly as the heating time increases. From these results, it is recognized that heated kerosene can be detected by our system as well as non-heated kerosene.

3.6. Imaging with burned samples

Next we have studied imaging heated kerosene with burned materials. Samples are wood, a carpet, a blanket, a towel, a cotton glove and a fuel container. These samples were burned with a portable gas burner. A fuel container is red in its original color but by burning it became white and ultimately it became almost transparent. Other samples were carbonized. After burning, heated kerosene for 5 min was dropped to the surface of burned samples. Resultant images

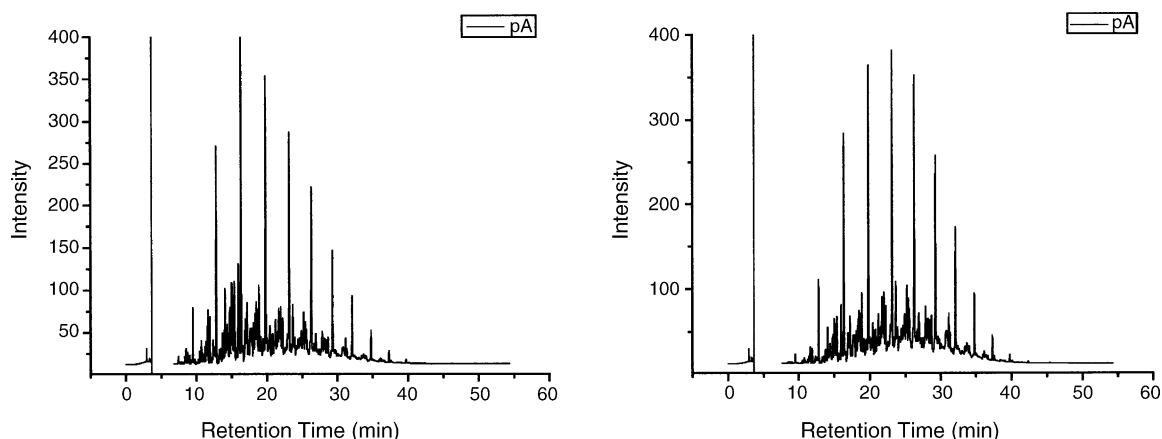


Fig. 16. Gas-chromatography charts for kerosene without heating (left) and with 5 min heating (right).

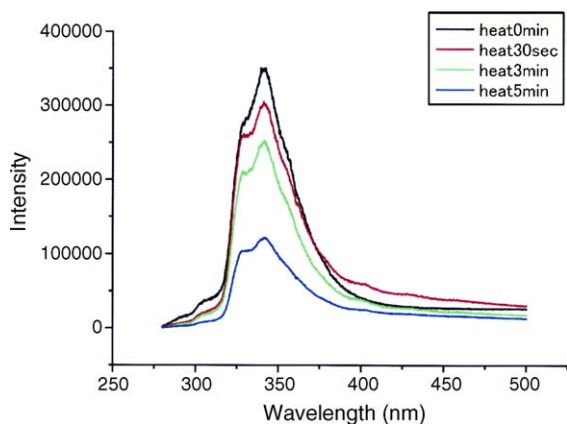


Fig. 17. Fluorescence spectra for non-heated and heated kerosene samples with 266-nm excitation.

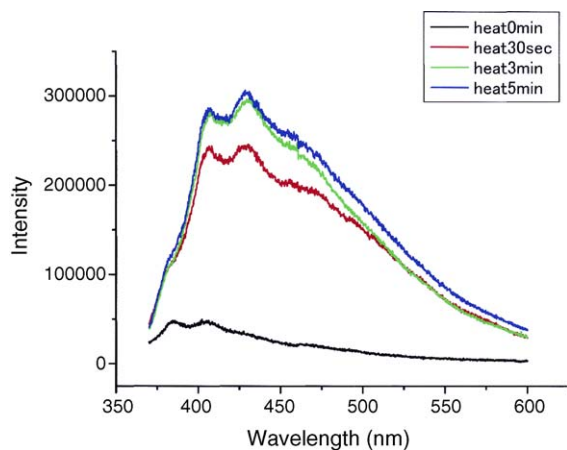


Fig. 18. Fluorescence spectra for non-heated and heated kerosene samples with 355-nm excitation.

are shown in Fig. 20. These images were obtained with a high-pass filter which cuts the incident laser light and passes fluorescence. Except for a non-burned fuel container and a cotton glove, kerosene was detected with 10 ns delay. For a fuel container, kerosene was not detected when a fuel container was not burned. This is because the fluorescence of a fuel container has the same spectrum range as kerosene below 400 nm. In Fig. 21, time-resolved fluorescence spectra of a non-burned fuel container are shown. The fluorescence of a non-burned fuel container ranges from 260 to 450 nm with several peaks. The lifetime of each spectral peak is shown in Table 3. The peaks above 340 nm have a longer lifetime of 17–23 ns than the peaks located below 330 nm which have a lifetime of approximately 8.5 ns. These peaks with longer lifetime make it difficult to visualize kerosene. This is the reason why a non-burned fuel container and a cotton glove could not be imaged clearly in Fig. 20. This problem can be solved by using a band-pass

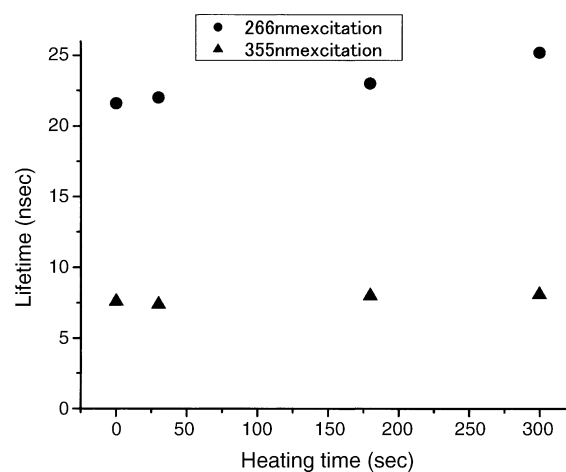


Fig. 19. Lifetimes for kerosene with various heating times.

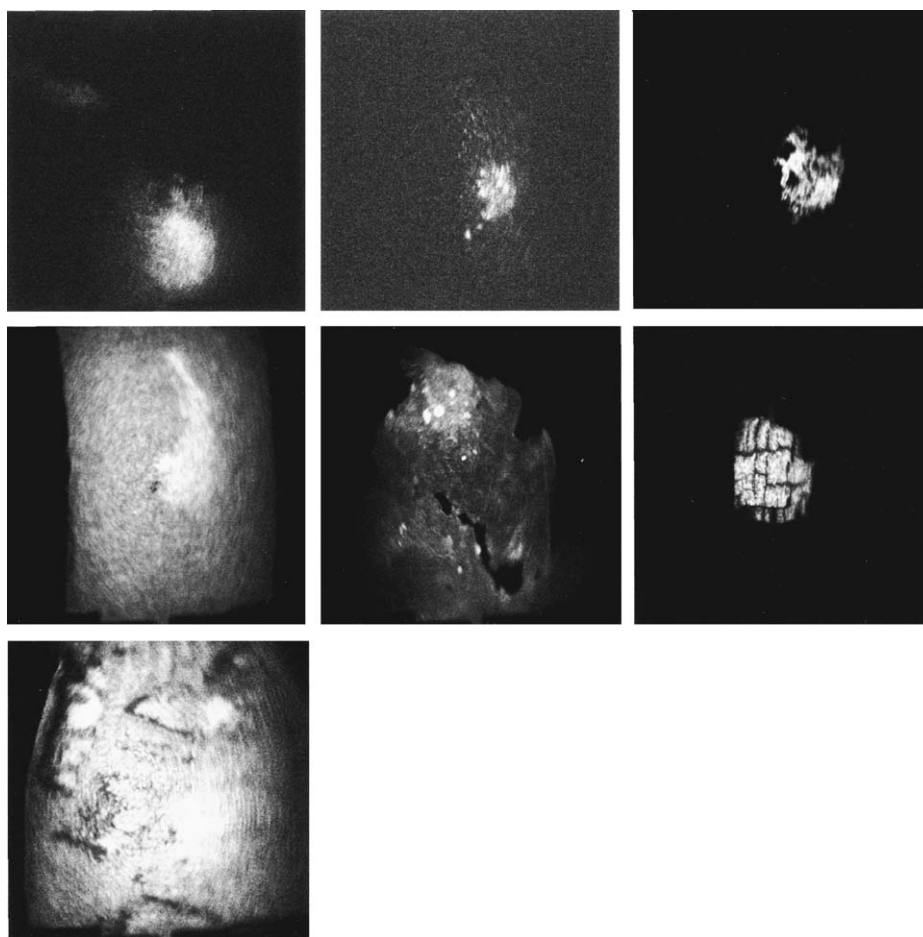


Fig. 20. Time-resolved fluorescence images of heated kerosene on various burned background materials. The delay time is 10 ns for all. From left upper corner: towel, blanket, carpet, fuel container (non-burned), fuel container (burned), wood and cotton glove.

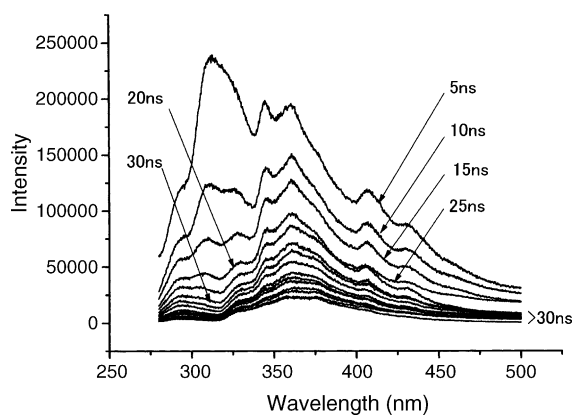


Fig. 21. Time-resolved fluorescence spectra of a non-burned fuel container.

filter U340 which passes fluorescence around 340 nm and filters out fluorescence of more than 400 nm. The result with the U340 filter is shown in Fig. 22. By time-resolved imaging with more than 10-ns delay, kerosene is visualized clearly. Thus, by filtering out fluorescence with more than 400 nm which has a long lifetime, fluorescence images of

Table 3

Lifetimes for non-burned fuel container and burned cotton glove

Sample	Peak position (nm)	Lifetime (ns)
Non-burned fuel container	310	8.7 ± 0.2
	313	8.2 ± 0.2
	345	17.4 ± 0.8
	358	22.4 ± 1.0
	407	19.5 ± 1.2
	432	17.6 ± 1.2
Burned cotton glove	395	4.72 ± 0.03
	455	5.96 ± 0.06

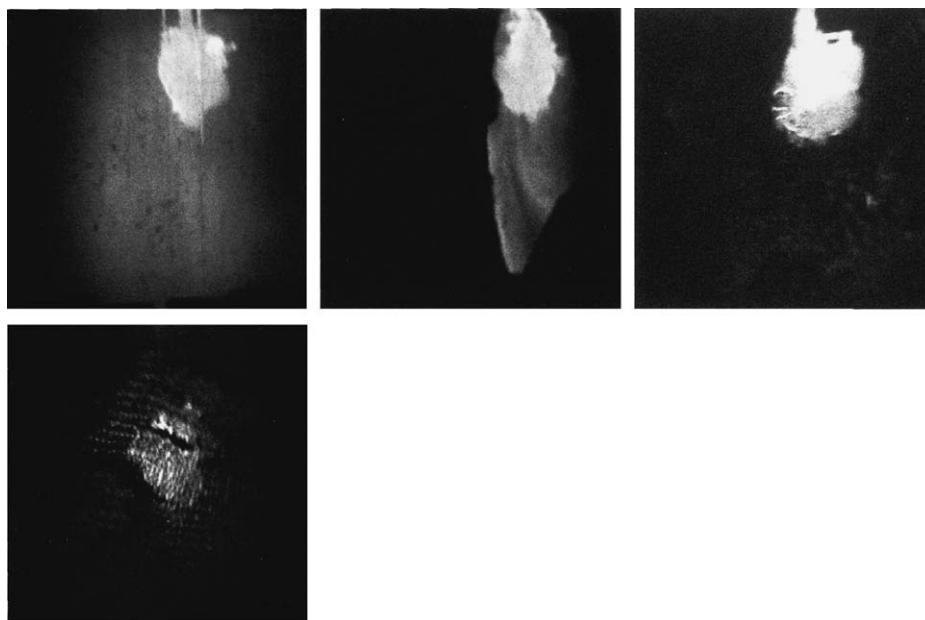


Fig. 22. Time-resolved fluorescence images of heated kerosene on a fuel container and a cotton glove. The delay time is 10 ns for all. From left upper corner: non-burned fuel container, burned (white) fuel container, burned (transparent) fuel container and cotton glove.

kerosene can be obtained even with a non-burned fuel container. For a burned fuel container and a burned cotton glove, the U340 filter is also effective for visualization. In Figs. 23–25, time-resolved fluorescence spectra for a burned fuel container and a burned cotton glove are shown. For a fuel container, fluorescence spectra varied by burning, i.e., lower components below 400 nm reduce their intensity and components above 400 nm become dominant, which leads to more effective visualization. In case of a burned cotton glove, there are two broad peaks at approximately 400 nm and 450 nm. The lower peak reduces faster than the higher peak. Their lifetimes are shown in Table 3. Therefore in this case, time resolved imaging becomes effective by using the

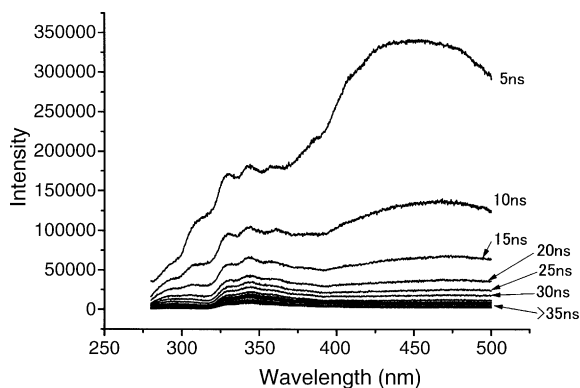


Fig. 23. Time-resolved fluorescence spectra of a fuel container burned to white.

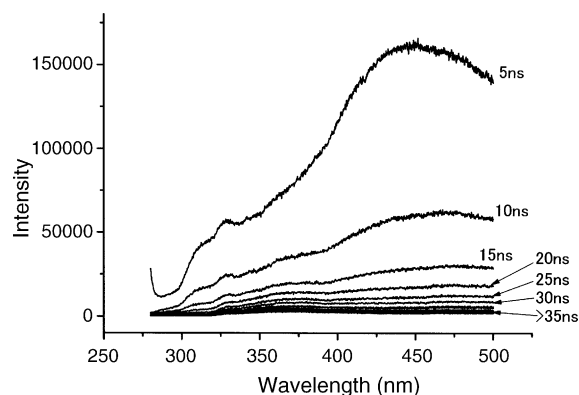


Fig. 24. Time-resolved fluorescence spectra of a fuel container burned to almost transparent.

U340 filter. Thus, it is not difficult to detect kerosene on burned samples.

4. Discussions

Petroleum accelerants consist of hydrocarbons including paraffin and aromatics. The optical property of hydrocarbons depends on the number of conjugated double-bond. That is, as the number of conjugated doublebond increases, the energy for the transition between two electronic states becomes lower, which means that hydrocarbons show stronger luminescence as they consists of more conjugated

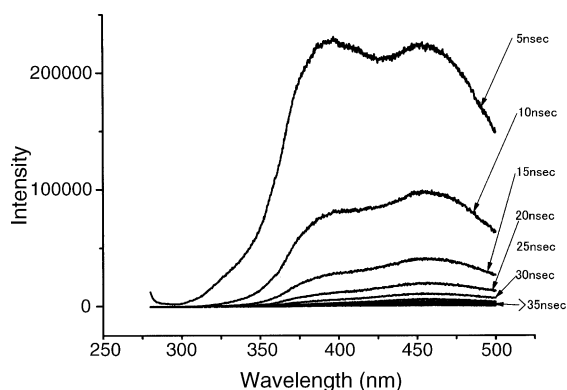


Fig. 25. Time-resolved fluorescence spectra of a burned cotton glove.

double-bonds. According to Ref. [6], petroleum includes benzene and naphthalene which are considered to emit strong fluorescence. In Fig. 26, fluorescence spectra of naphthalene compounds excited at 266 nm are shown with those of kerosene. As can be seen from Fig. 26, fluorescence spectra of kerosene almost coincide with those of dimethylnaphthalene. Therefore, it is estimated that fluorescence of kerosene stems from dimethylnaphthalene. The component corresponding to dimethylnaphthalene is also recognized in the fluorescence spectra of diesel fuel with 266-nm excitation. However in the cases of gasoline and diesel fuel, those fluorescence spectra show several peaks which are not apparent to correspond to naphthalene compounds.

In the case of 266-nm excitation, the fluorescence spectra of kerosene and gasoline show no components above 400 nm. On the contrary, several peaks are observed above 400 nm for 355-nm excitation. Therefore, it can be said that the components excited by 355 nm light are not excited by 266 nm light. However for diesel fuel, there exists a different situation. In this case, fluorescence spectra show almost the same profile above 380 nm wavelength for both excitations.

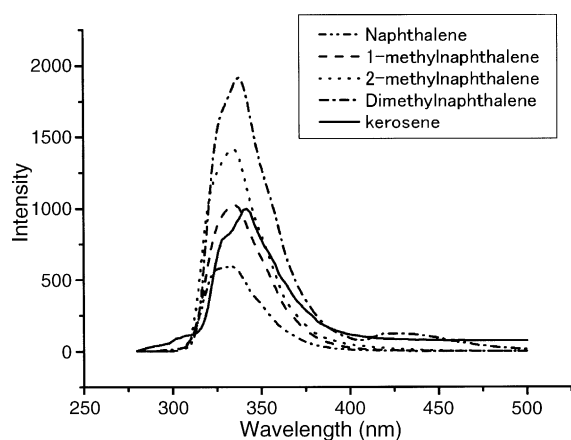


Fig. 26. Fluorescence spectra of naphthalene compounds and kerosene for 266-nm excitation.

Therefore in case of diesel fuel, the same components may be excited for both 266-nm and 355-nm excitations.

Comparing the fluorescence spectra of petroleum accelerants, a clear difference exists for spectrum profile and its lifetime. This means that kerosene, gasoline and diesel fuel can be distinguished by using fluorescence spectra. Petroleum accelerants are usually analyzed and identified by gas chromatography. But in actual arson scenes, we do not have an effective method for detecting petroleum accelerants so far. In actual cases, it is very important to detect and collect evidence. We have shown that heated kerosene can be detected even on burned samples. Therefore, our method can be used for detecting petroleum accelerants in actual scenes. After detecting and collecting samples of petroleum accelerants, analysis by gas chromatography is useful. To employ our method in actual scenes, we can use a portable system with a portable Nd-YAG laser and a cooled CCD camera.

5. Conclusion

We have studied ultraviolet fluorescence of petroleum accelerants such as kerosene, motor gasoline and diesel fuel with 266-nm and 355-nm excitation of a pulsed Nd-YAG laser. We have measured time-resolved fluorescence spectra of petroleum accelerants and various background materials and obtained their lifetimes. Since the lifetime of petroleum accelerants is longer than that of background materials we measured, it is recognized that petroleum accelerants on various background materials can be imaged clearly with more than 10-ns delay. In the case of heated kerosene, there are some changes in composition of kerosene, spectral profile and intensity but there is a difference between 266-nm and 355-nm excitation. On imaging heated kerosene with burned background materials, kerosene was confirmed for most materials which were not made of petroleum. But in the case of petroleum-origin materials such as a fuel container, there is an overlap between the fluorescence spectrum of kerosene and that of a fuel container. Therefore, it is necessary to use an appropriate band-pass filter for visualization. By burning, such an overlap reduces, and therefore kerosene can be detected more clearly.

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